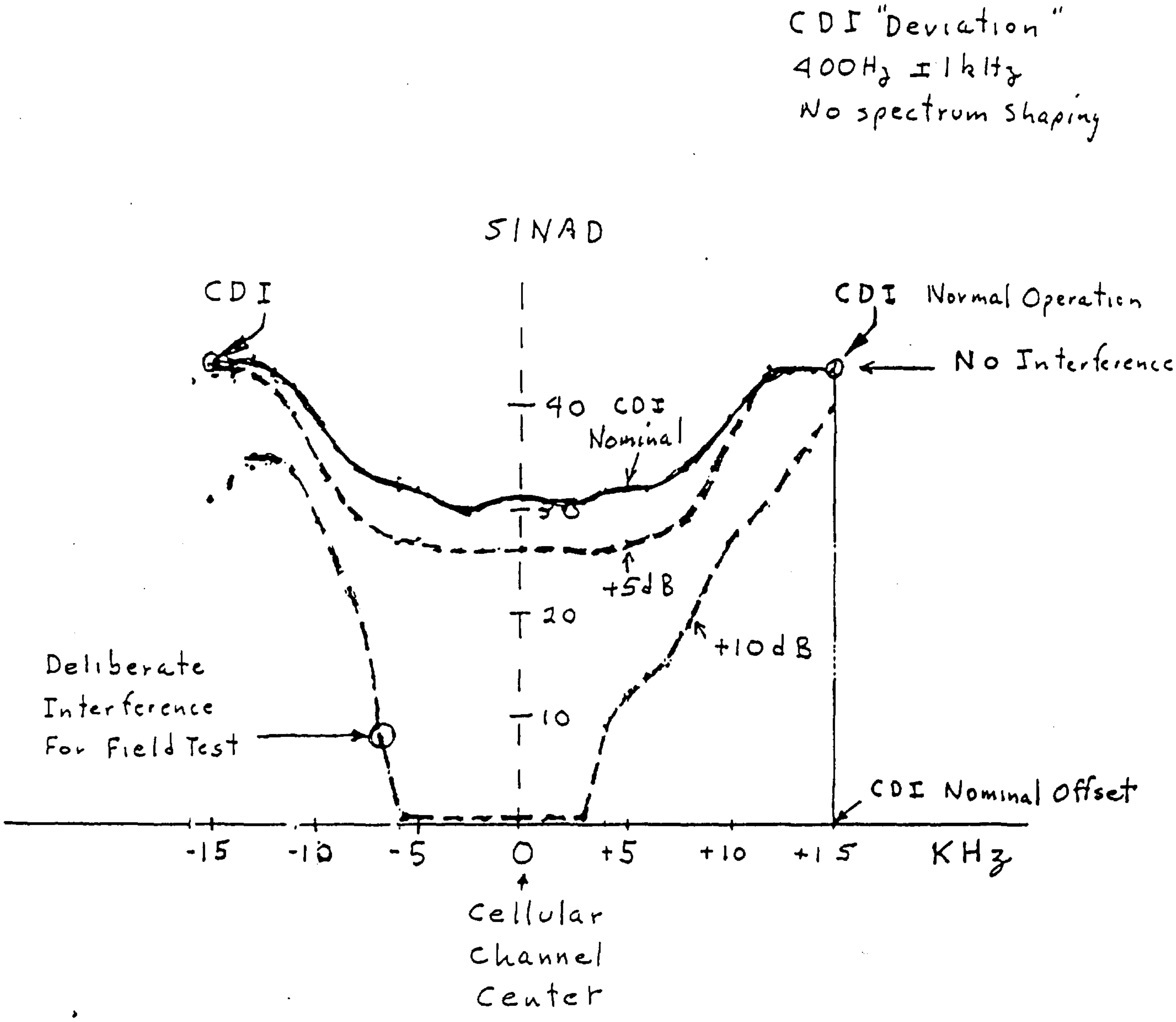


FIGURE 34 - Bench Test: Mobile sensitivity to CDI interferer at nominal power and frequency separation and at 5dB and 10dB higher power and smaller frequency separation.

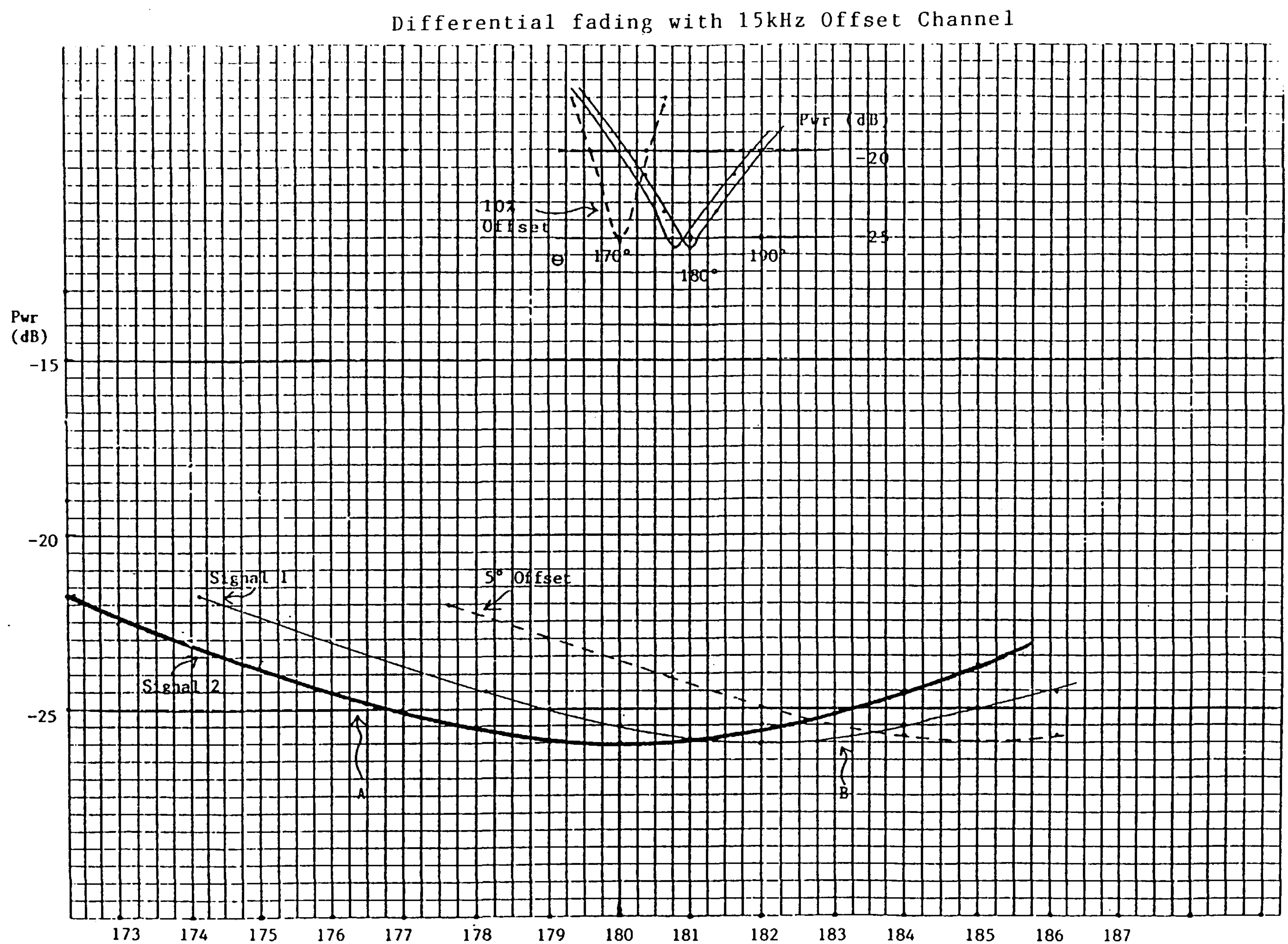
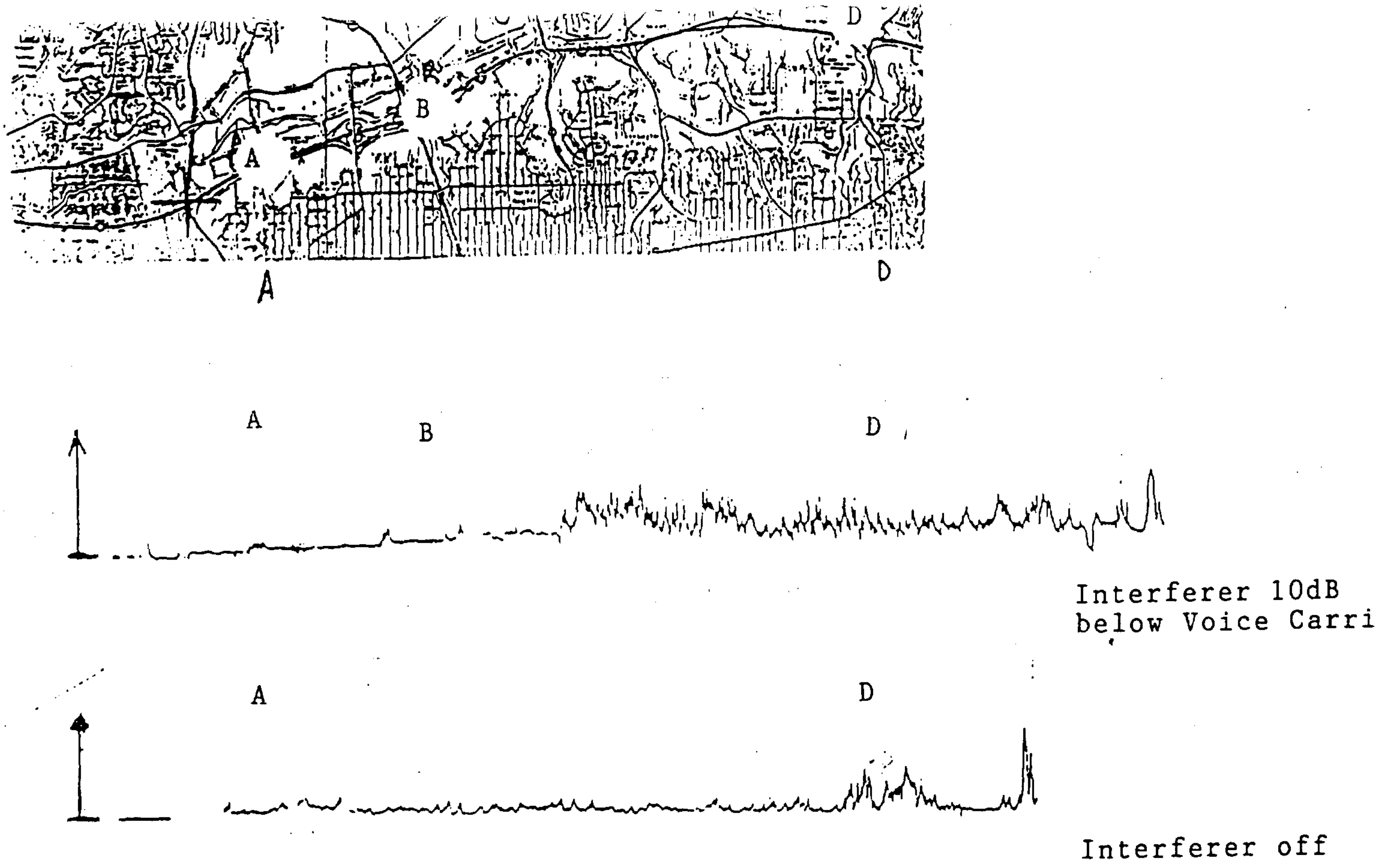
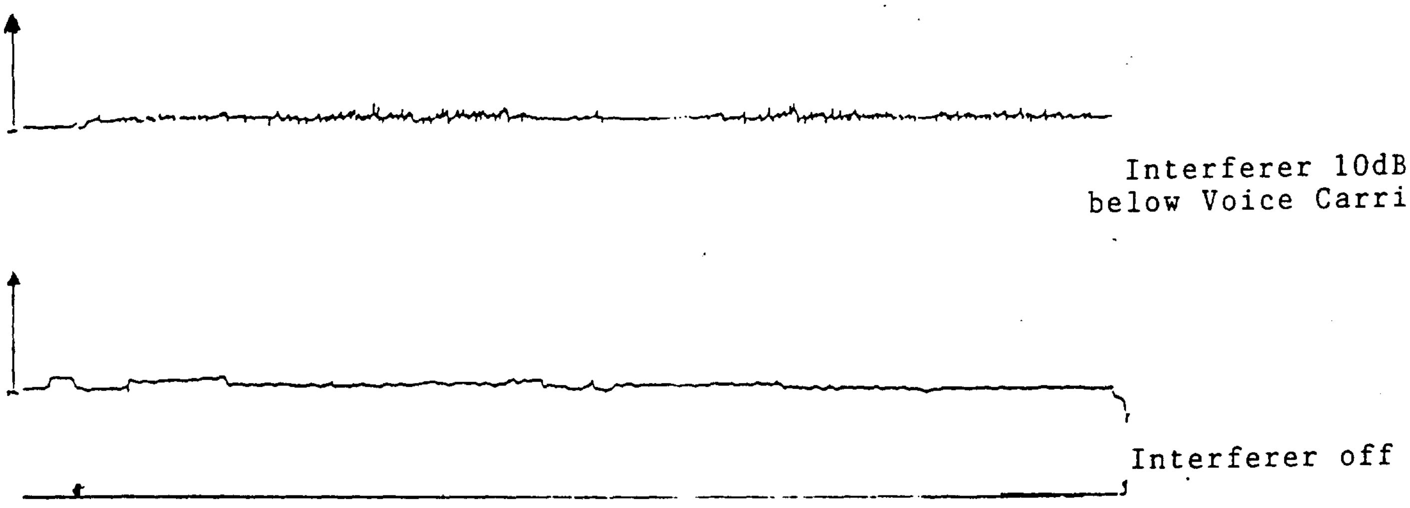

Differential fading with 15kHz Offset Channel
Pwr (dB)
-15
-20
-25
Signal 1
Signal 2
5° Offset
A
B
10% Offset
Pwr (dB)
-20
-25
θ
170°
180°
190°
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187

FIGURE 35



(a) Interference Along I-8



(b) Interference around Base site building

FIGURE 36

Co-Channel Interference in Reference Cell

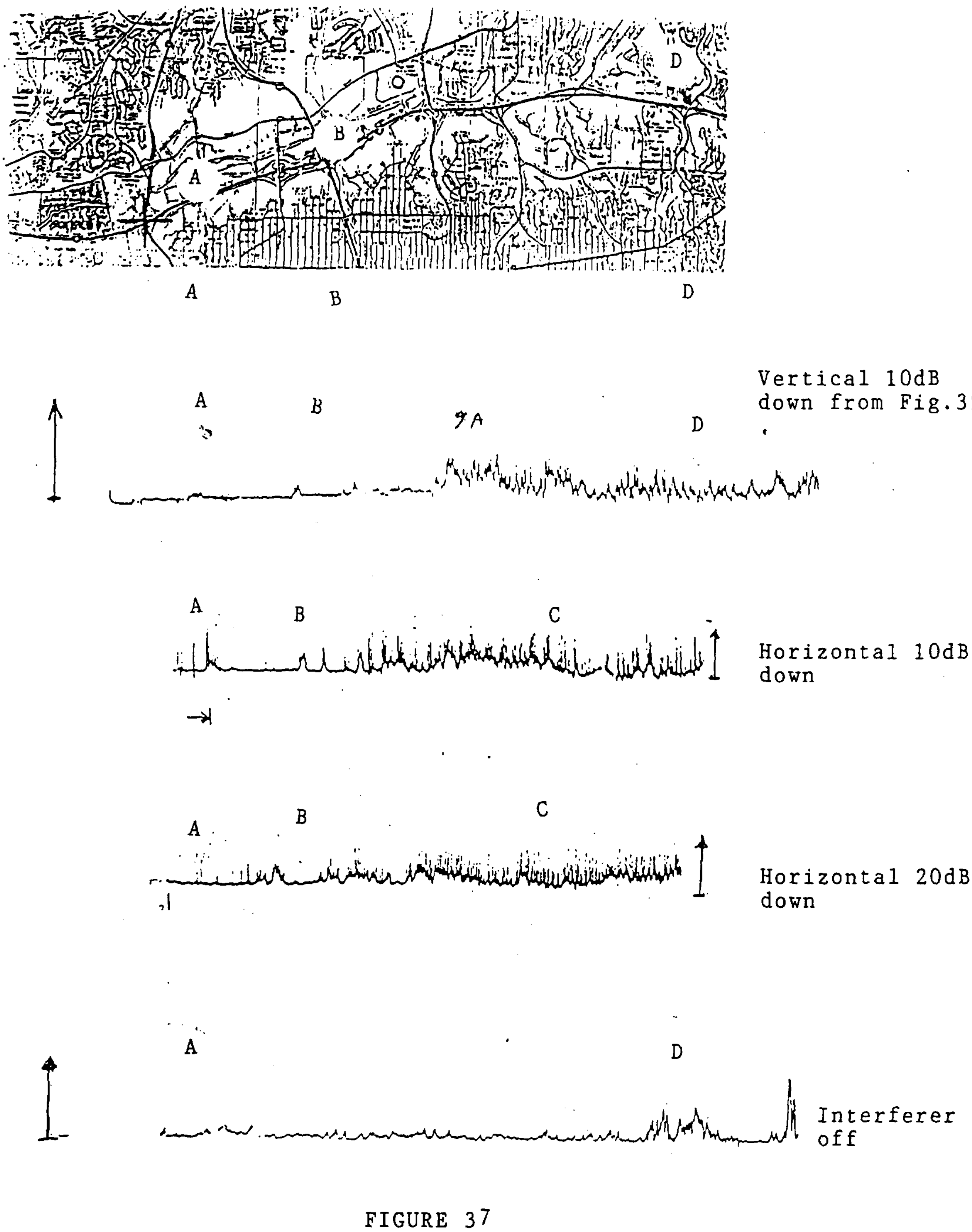


FIGURE 37

Co-Channel Interference in Reference Cell with Cross-Polarization

VI INBOUND REFERENCE CELLULAR TESTS

In the Cell the inbound signals from the User transponders may cause interference to the Cellular Mobile vehicles receiving service in the Cell. The level of the CDI transmissions must be controlled to avoid such interference.

The way this is done is shown in Figure 38. In all normal Cellular installations the receiving antenna for the Cell is connected to a distribution pre-amplifier. Figure 38(a) shows a block diagram of the typical installation. The pre-amplifier amplifies the entire spectrum of the Cellular receive spectrum and sends the amplified signals to a number of output ports. The Cellular receivers assigned to that antenna coverage area are all attached to that amplifier. They all experience the same limiting noise figure since the noise limit is set by the same front end electronics.

In the Cellular operation the Mobiles are power controlled so that their signal levels incoming to the Base station are a reasonable margin above this noise level, but no more than is necessary to give a clean signal. this is typically 25 to 35dB above the noise floor in order to give proper fading margin. If the mobile signal level becomes stronger than this for any period of time, a command is sent to reduce the power level. The feed-back is used to reduce the probability of interference to adjacent cells and to the Re-use cell.

The CDI Base station receiver is to be attached to the same distribution amplifier. The CDI Base station receiver (like the Cellular system) also controls the level of the signals arriving from the User transceivers. It is equipped with a level measurement good to ± 3dB accuracy. If the signal commanded from the User transponder arrives with more strength than desired, the outgoing CDI channel commands the User unit to reduce its' power.

The CDI signal is commanded to be within ± 3dB of a target noise level of the receiver pre-amplifier. The level is chosen so that the incoming Mobile signal, when it encounters a fade, will drop into the pre-amplifier noise limitation before it drops into the CDI signal 15kHz away.

Figure 38(b) shows the output of the distribution pre-amplifier at the Mt. Ada Test site. In this example, the mobile carrier is at a level approximately 20dB below the level of the Cellular voice signal 15kHz away. The signal at this level is just about at the level that causes negligible interference on the test runs.

For a margin of safety, the signal would normally be run approximately 5dB lower. Note: that the CDI receiver at this level still has a 20dB carrier to noise ratio above the noise floor of the common pre-amplifier and antenna.

In this configuration, the Cellular Voice signal has a 36dB carrier to noise ratio above the noise floor of the common pre-amplifier and antenna. This level accounts for an FM threshold of about 13dB and a fading margin of twenty to 25dB.

In the tests done three issues were checked to confirm the procedure for CDI to operate without interference to the Cellular Voice channel.

The first issue was the ability of the CDI User transponder to maintain a constant level into the Base station pre-amplifier. The control functions are built into the Transponder Design and is part of its required specifications. The only issue is whether the power level might vary too rapidly to be reliably controlled.

To test the steadiness of the path, a simulated User transceiver was set to transmit from the remote site within the cell. A chart recording was made from the time CDI was allowed to start transmitting, 7:30p.m. until early the following morning. The signal remained steady within two or 3dB throughout almost all of this period. A few events dropped the signal about 5dB with a rise to the initial level after. The events were slow and were attributed to persons passing in front of the user transponder. The speed of the event would provide no difficulty to the CDI power control system.

The second issue was whether the incoming Cellular signal would often rise high enough to cause CDI loss of data for any protracted time.

The power level of the test mobile was monitored as the mobile was run from the cell center to the cell edge. The average power (not including fading nulls) varied only within about 15 to 20dB, varying up and down from the level shown. The active control from the Cellular switch could be seen to reduce the mobile power level as the mobile came closer to the cell center.

This issue is of concern to CDI's data integrity. The data system is designed to receive interference from the adjacent channel at these levels, accepting "hits" from sporadic bursts of speech and re-transmitting the data necessary.

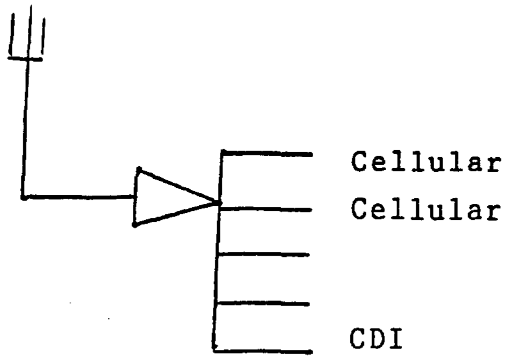
The third issue was the level at which the CDI User transponder would cause no interference. Figure 39 shows test runs in the Mt. Ada Cell. The CDI signals were set at various levels relative to the noise floor. The mobile was run from the cell center toward the cell adge (from A to B).

Four runs were made. In all, the CDI signal was 15kHz from the Cellular channel. The carrier to noise of the CDI signal was set at 20dB, 30dB, 40dB and 50dB. As can be seen in Figure 39, the interference became negligible at the 20dB C/N level as expected.

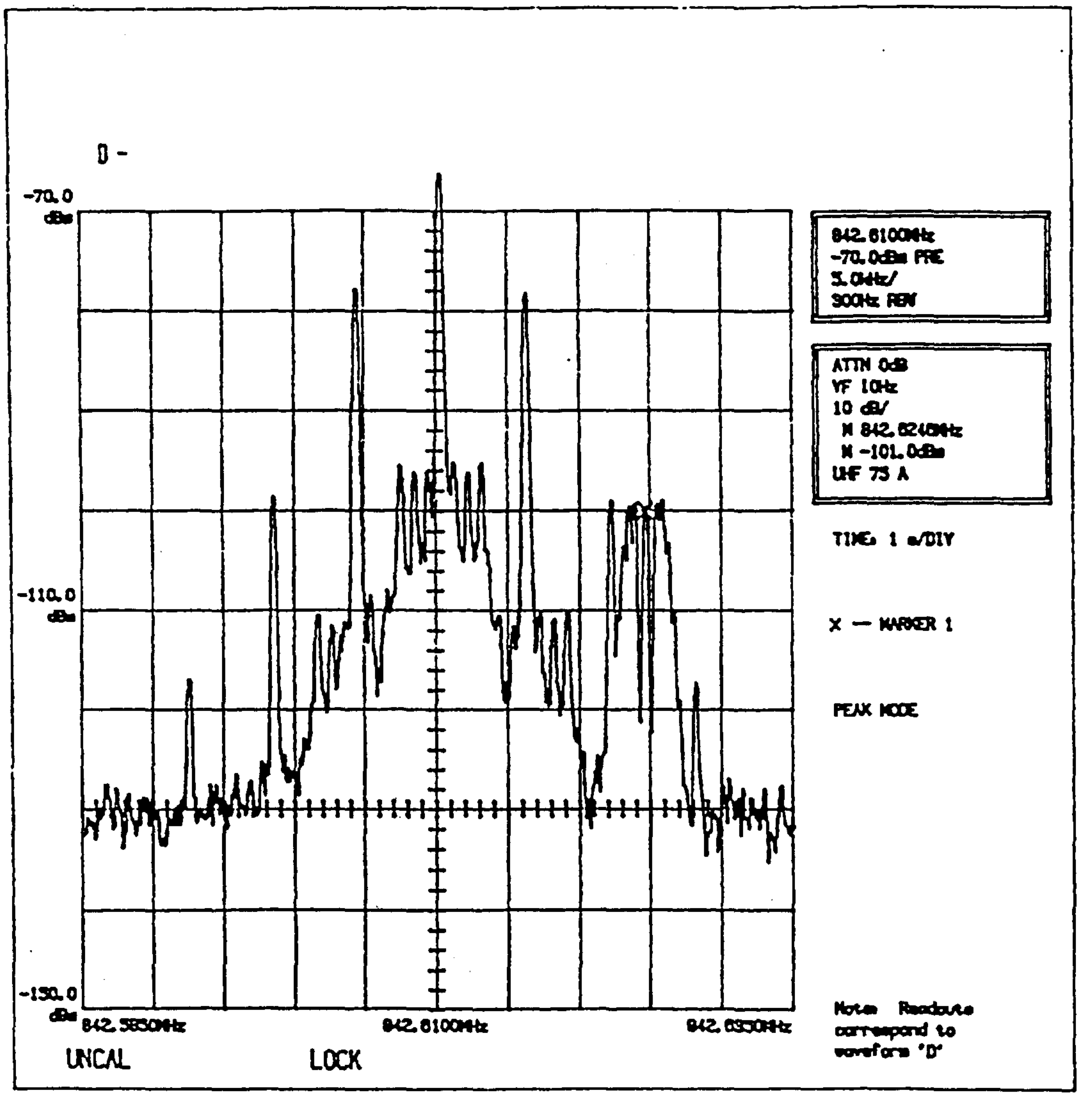
These tests confirmed that within the reference cell the CDI User transponders can be controlled at a level that causes no interference to the Cellular service and yet maintains enough signal strength to provide reliable service to the CDI data system.

The coordination procedures of the Cellular operators requires that Adjacent-channel cells be located at least two cells away and that co-channel Re-use cells be located at least three cells away. The separation distances for these cells to serve the Cellular coordination needs guarantees that the CDI User transponders will have much less signal strength in the Re-use and adjacent channel cells. Meeting the Reference cell criteria (i.e.. 20dB C/N) virtually guarantees non-interference in the other cells.

If the CDI User transponders are installed within the normal reference cell boundaries, no further precautions should be necessary. If for some reason some installation is made beyond the normal cell boundary (i.e.. to take advantage of some high terrain or a convenient installation point) only then should a further check be made. Building shielding or a directive antenna on the CDI unit might be used in this case to ensure protection of the other cells.



(a) Common Distribution Amplifier



(b) Received Spectrum

FIGURE 38

Inbound Receivers

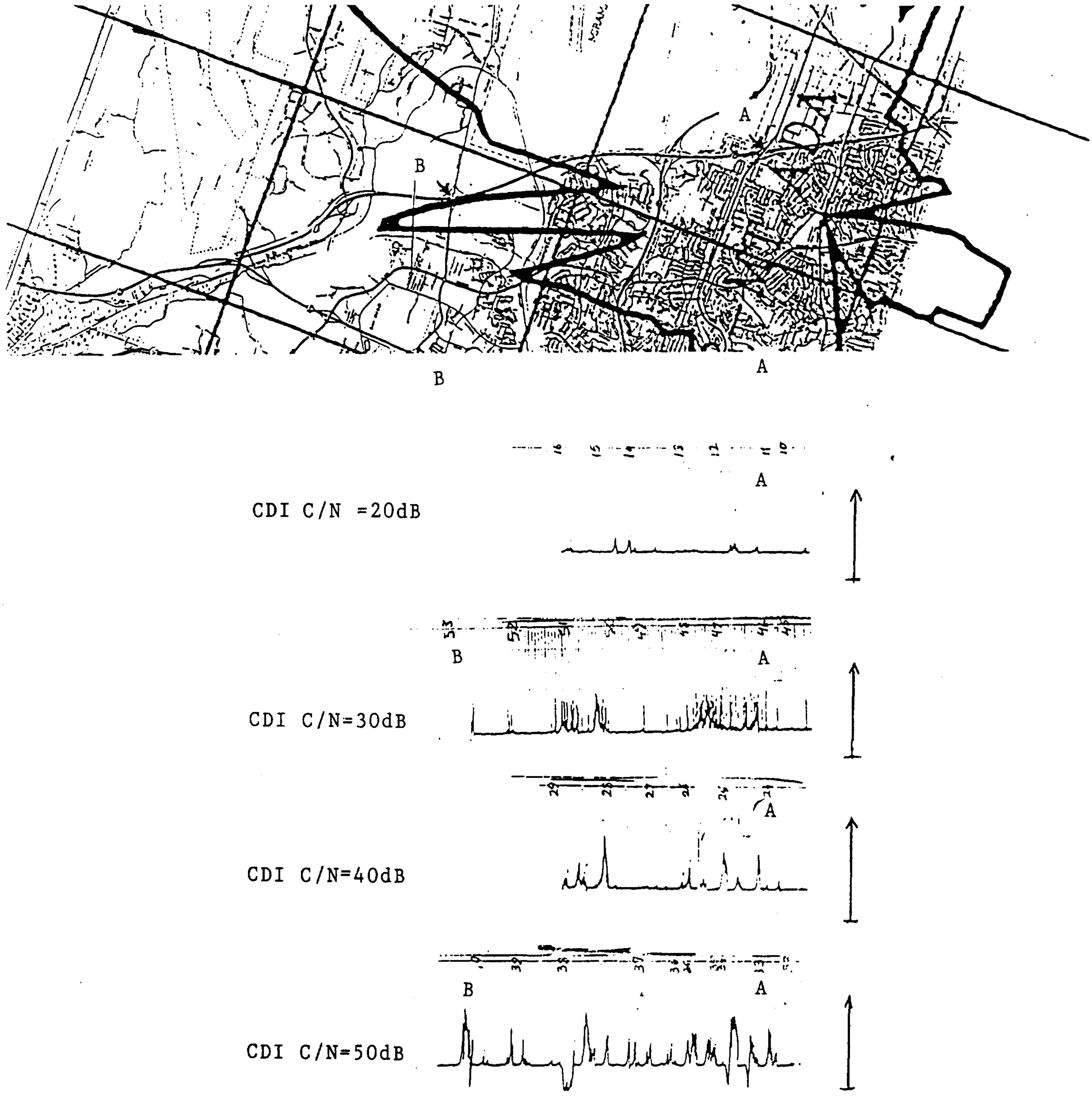


FIGURE 39
Inbound Interference Tests

VII CO-CHANNEL RE-USE TEST

The CDI signals are designed to avoid interference within the Reference cell. When the same Cellular frequencies are used again in a Re-use cell at a great distance, it is very unlikely that the CDI signals in the Reference cell will interfere with normal Cellular service in the Re-use cell. In the Re-use cell, the CDI signals are expected to be much weaker because of the distance. None the less, it was appropriate to check this. For this test, the channel with the 1kHz test tone was transmitted from the Re-use cell. A clean signal (no interference) is obtained when the Re-use signal is received.

Interference results from any of three sources, when the Re-use signal is lost because of fading, when the CDI Reference cell cell test signal interferes with the Re-use signal, or then the Reference cell voice signal with Harvard Sentences 'itself interferes with the Re-use channel.

The results of these tests are shown in Figure 40. The Reference cell is Mission Valley. The Re-use cell is Carlsbad. The normal 37dB contour of the Reference cell runs the right up to about point C on the test path. The coverage of the Carlsbad cell runs from the left nearly to point D on the test path. Both coverages are shown by arrows beneath the map.

The three test runs shown correspond to three different CDI signal levels. On the upper trace, the CDI signals were only 7kHz off the Cellular frequency and of equal power. This was done to deliberately increase the potential of CDI interference. In the second, the signal was moved 15kHz away from the Voice signal and reduced to 10dB below the Voice signal. In the third, bottom run the CDI test signal was "off". Interference would result only from the normal Cellular transmissions carrying the "Harvard Sentences".

Inspection of the three runs shown leads to the following conclusions: Within the Carlsbad Re-use cell there is no evidence of either the CDI Data signal or the Mission Valley Cellular Voice signal. The interference shown towards the edge of coverage is due to fading caused by terrain shadowing. This fading shows up whether the CDI signal was on or not.

From the edge of coverage through to point (C) on the test run, the Carlsbad signal fades in and out. From Point (C) onward to the center of the Mission Valley site, the Carlsbad signal is interfered with by the Mission Valley transmission. This is, of course, expected since Mission Valley is a Re-use cell for Carlsbad and the mobile receiver is in the wrong cell.

From point (C) through (A), the interference pattern is due to transmissions from the Mission Valley Transmitter, either from the Cellular Voice Channel, the CDI signal or both; the interference varies in the three runs. On the top run, where the CDI signal is equal in strength and only 7kHz away from the Cellular channel, both Voice and CDI interference are seen. (Listening to the tape also confirms than both are present.)

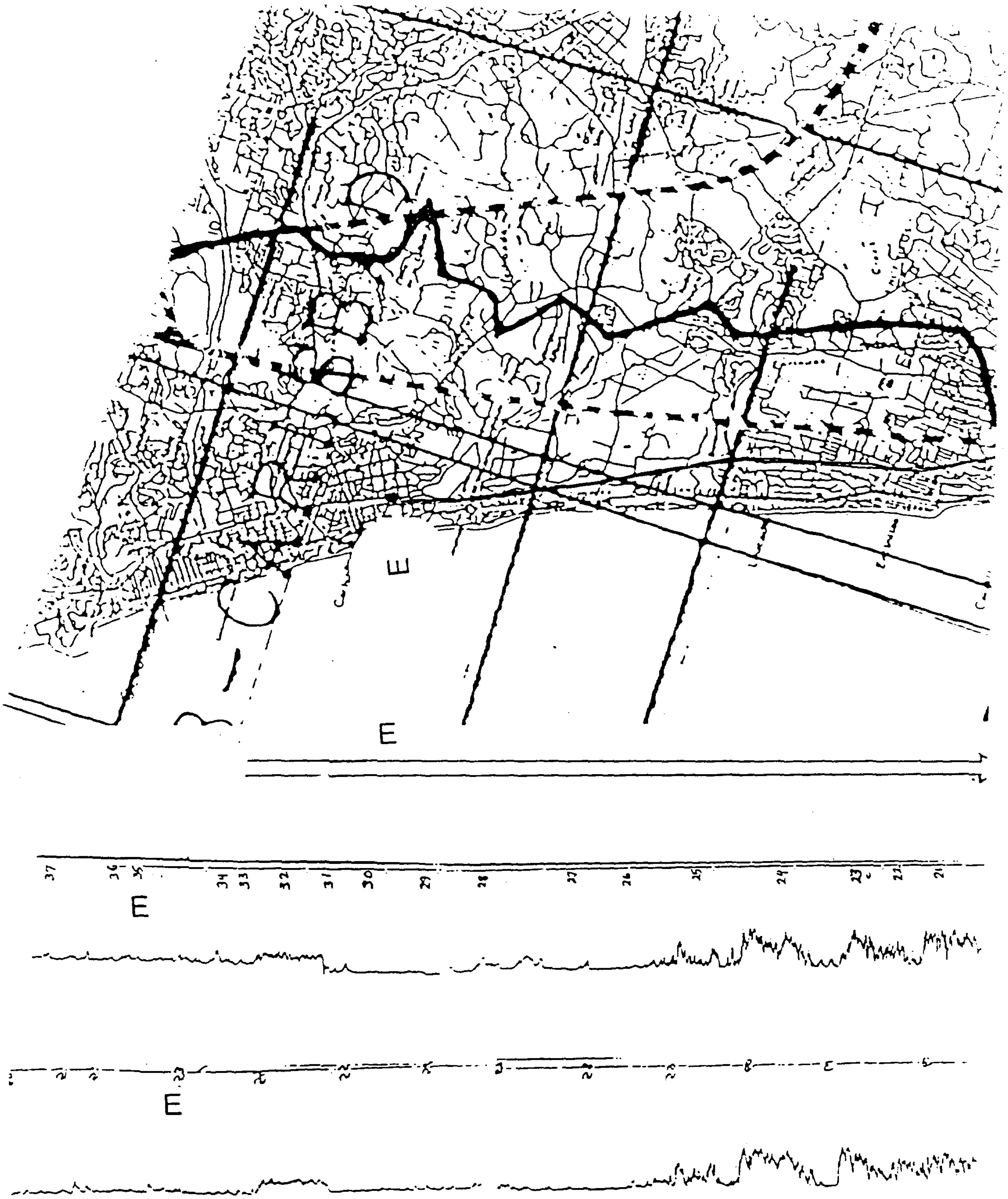
On the bottom run, where the CDI signal is "off", the interference, due to the Cellular Voice channel, is still apparent (listening still shows the Harvard Sentences). In the middle trace, where the CDI signal is at its normal frequency (15kHz off the voice channel) and 10dB lower in power than the normal Cellular transmission, the interference is due to the Voice channel, not the CDI signal.

Note that the CDI signal will normally be run 20dB to 25dB lower than the Voice channel, not just 10dB lower.

The conclusion is that the CDI signal, when operated at its' normal level in the Reference cell will not cause interference to service in the Re-use cell. The interference potential of the normal Reference Cell Voice channel is much, much greater than the CDI signal.

One side observation can be made. Note that at Point (C), the interference is gone. The receiver is clearly receiving the signal from Carlsbad rather than the Harvard sentences from the Mission Valley Cellular transmissions. Point (C) is within the nominal coverage area of Mission Valley, yet the Mission Valley transmission is captured by the Carlsbad transmission about three cells away.

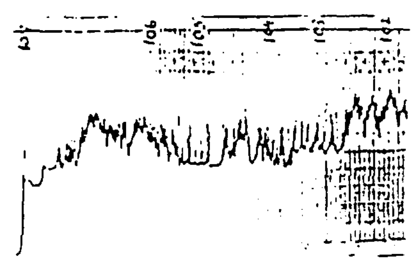
The Cellular to Cellular interference illustrates why the large Re-use distances are necessary in Cellular frequency coordination. Because this interference potential must be controlled, the Re-use distance will always be great enough to keep such co-channel interference within tolerable limits. This Re-use distance will thus always guarantee that the CDI signals will be non-interfering in the Re-use cell.



A) CDI Signal 7kHz Off Equal Power

B) CDI Signal 15kHz Off 10dB Down

C) CDI Signal Off



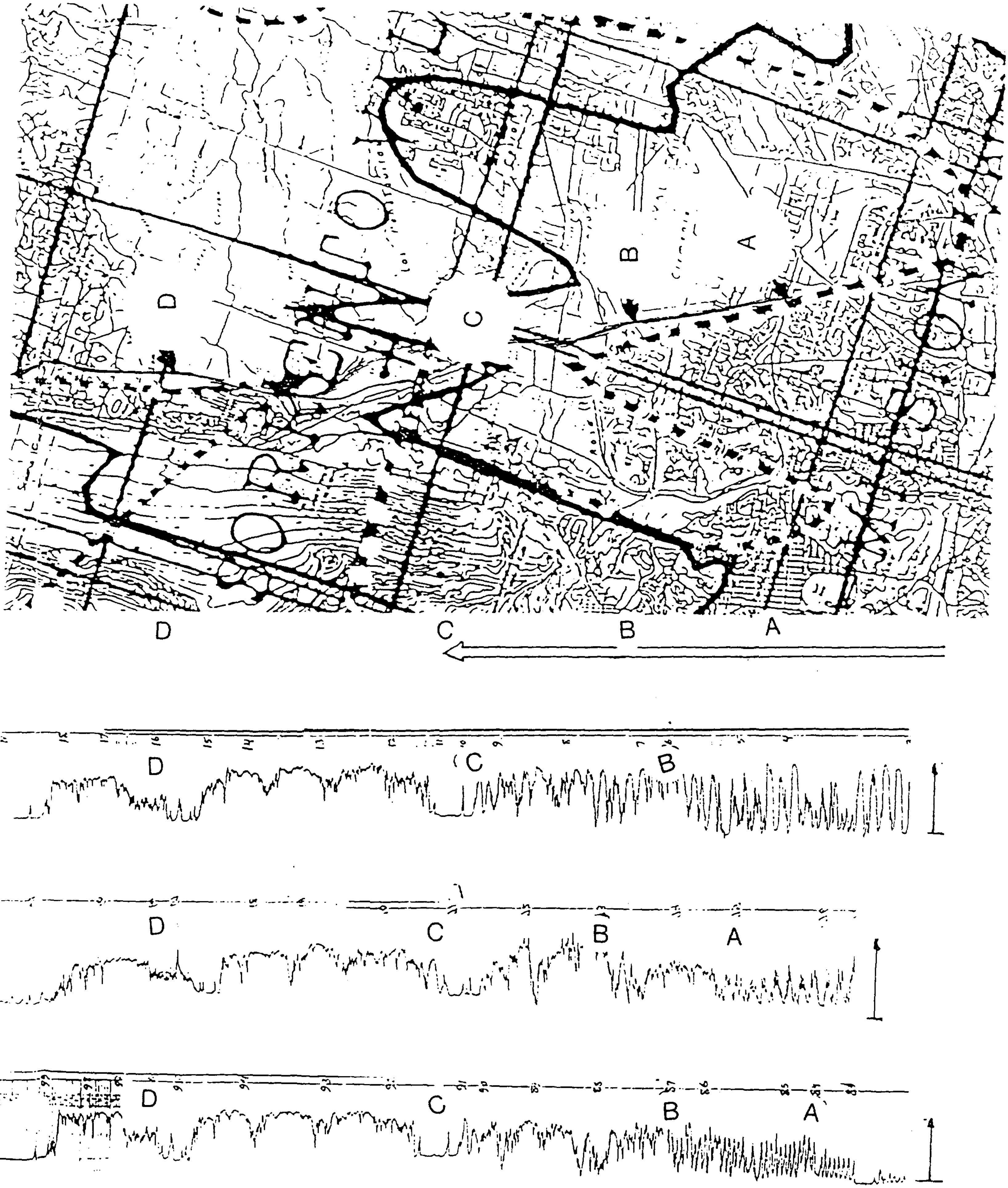


FIGURE 40
Tests in Co-Channel Re-use Cell

VIII ADJACENT CHANNEL TESTS

The same procedure described in detail in the Co-channel Re-use tests was used to measure the interference in the Adjacent-channel cells. In this test, the Mission Valley cell was the Reference cell and the Sorrento Valley cell was the Adjacent-channel cell.

The procedures used were the same as described in detail in the previous section on the Re-use tests. The results are shown in Figure 41. The Sorrento Valley cell transmitting the wanted signal is to the left. Its' coverage area stops around Point (B) on the test run. The Mission Valley coverage area is at the right and stops halfway between Point (C) and (D) on the test run.

The CDI test signal is run 15kHz off of the Cellular Voice carrier, halfway between the Mission Valley Cellular Voice signal and the Sorrento Valley Cellular Voice signal. Its' level is only 10dB lower than the Mission Valley Voice carrier (this is 15dB higher than the normal level.)

The top curve of Figure 41 shows that the interference to the Sorrento Valley cell stops before the test Mobile even leaves the Mission Valley cell area. No interference results from the Mission Valley transmissions to the left of Point (C). From that point on, the Sorrento Valley cell has an interference free signal.

The lower curve shows the signal from Sorrento Valley with the interferer off.

These and similar runs confirm that adjacent-channel cells will not be interfered with by the CDI transmissions in the Reference cell.

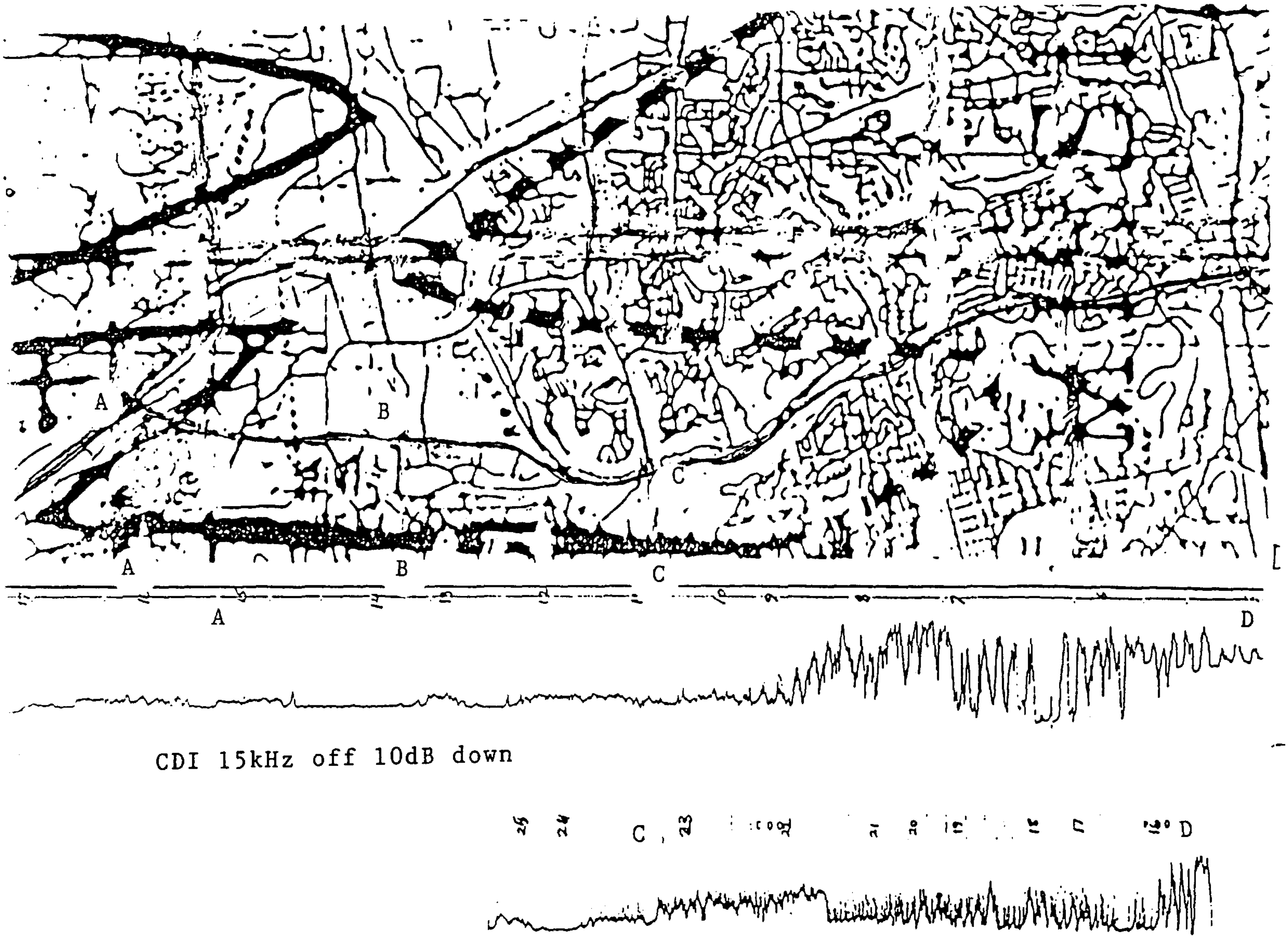


FIGURE 41

Adjacent Channel Interference

IX CROSS POLARIZATION

(a) Antenna Patterns

Improved separation between the CDI and the Cellular system is achieved by using horizontal polarization in the CDI system. CDI can use horizontal polarization on the path from Base Station to User Transponders, on the path from User Transponder to Base Station, or both. The decision will be based on the local installation convenience and may vary from system to system. (The CDI User transponder is designed to use either the same linear polarization on both transmit and receive or to use cross polarized transmit and receive antennas.)

Tests were run in the Mission Valley Cellular site to measure the polarization isolation. It was necessary to place CDI test antennas up at night and remove them in the morning., This limited the antenna design and the degree of horizontal polarization accuracy that could be obtained.

Figure 42(a) shows an ideal way to mount a horizontally polarized antenna (a loop) together with the standard omni-directional linear antenna used at the site. Figure 42(b) shows the actual antenna used on the site. The loop is mounted to one side of the linear near its base and the feed line runs up one side of the loop. The result is a horizontally polarized signal in most directions, but poor polarization in some sectors of the cell. There also is a variation in antenna gain due to the shadowing of the horizontal loop antenna by the vertical pole antenna. (In an operational system, the loop would be run around the pole and fed with a horizontal line rather than a vertical one, reducing the variation in the pattern and giving good horizontal polarization in all directions. On edge-fed cells, it is simple to mount two linear directional antennas at right angles. (See Figure 42(c).)

In the field tests, the polarization was measure at 16 locations around the coverage area, Figure 43. The test set-up (see Figure 44) radiated 22dB EIRP from the vertically polarized Voice signal of the Cellular service and 9dB EIRP from the horizontally polarized data signal of the CDI service. The two signals were 15kHz apart in frequency. To measure the polarization at a distance, a test dipole was used. It was mounted at the end of a non-conducting pole and pointed towards the base site with a clear path for at least 50 ft. in the direction of the base site. The dipole was rotated in 45° steps through 360°. Signal strengths were thus measured two times at each polarization angle (0° and 180° will give the same readings.)

Both transmitted signals, Voice and Data, were measured at the same time using a spectrum analyzer. The results were repeatable within 5dB in all cases and more usually within 1 or 2dB. The polarization measurements for the 16 locations are shown in Figure 45. The Cellular Voice signal is shown by (+'s) and the CDI Data signal by (0's). The plot for location 1 is typical of a "clean" area. The maximum power received on the vertical Voice a "clean" area. The maximum power received on the vertical Voice signal was -47dBm at 90° (Vertical) and a minimum of -75dBm at 0° (horizontal). The maximum of the horizontal, Data, signal was -60dBm at 0° (horizontal) and -75dBm at 90° (vertical). The Data signal was 14dB lower than the Voice signal as expected. The linear polarization was sharper (33dB axial ratio) than the horizontal (16dB axial ratio) due to limitations of the CDI test antenna.

The results of this polarization survey are shown in Table A. There is one particular anomaly in the pattern of the horizontally polarized antenna. At an azimuth of about 272° the gain relative to the linear appears to be 8 to 10dB lower than in other directions. This is believed to be due to shadowing. Other variations are smaller and appear to be due to local structures or weak signals reducing measurement accuracy.

One anomaly also appeared on the vertical antenna. On locations 15, the axis is apparently tilted by 45° from vertical. The cause of this is not clear; It may be due to diffraction. The site is on the edge of a cliff overlooking the Base Station.

In any event, these two anomalies appear to be real and reduced the polarization isolation achieved in the installation measurements made the next day.

The polarization survey showed that relatively good integrity of polarization can be achieved on a Base site. If the antenna is made with good polarization behavior over the radiation pattern, in the majority of cases the polarization will be maintained over the coverage area. (An exception is the area right under the Base site building; this is covered in section (c).

(b) Polarization Protection

On the next day the same signals were transmitted from the Mission Valley Test site. User "installations" were simulated in the areas where the arriving polarization was measured on the previous day. The "installation" was made in the same way that a professional CDI installer would be instructed to make an installation. A test dipole was used as a CDI receiver. The dipole was held with the dipole in the horizontal plane and rotated about the vertical axis to peak the signal strength. The dipole has a very wide main antenna lobe and this peaking was not very critical. Precision of about $\pm$ 30° in rotation was typical. The interfering voice signal was not watched during this set up. In normal installations the CDI user unit would have a logical location, i.e. next to the burglar alarm, on a power pole, etc. To simulate such installations the test team designated installation points, set the receiver up and took the readings without any further adjustments. The level of the Data signal (CDI) was read and then the level of the Voice (Cellular) signal was read. Both were read from the spectrum analyzer without changing the position of of the antenna. This measurement automatically gives the isolation between the wanted CDI signal and the interfering Cellular signals.

The resulting wanted and interfering signal levels were then compared with the strength and polarizations of the signals entering the area.

The "installations" were selected to illustrate a wide range of situations that would be encountered in the CDI applications. The results both showed the attenuations encountered in typical installations and the typical polarization isolation achieved.

The installations included:

1) underground parking garage; 2) above ground, four level concrete structure; 3) residential areas outside houses; 4) metal and concrete wall installations of commercial buildings; 5) in shadow of condominiums; 6) throughout the interior of a restaurant; 7) in alleys and behind cyclone fencing; 8) power pole and residential sites; 9) around residential block (receiver was used inside station-wagon to simulate structural blockage); 11) on all sides of vertical metal pylons; 12) inside metal compartments of mobile trailer; 13) different pole heights for power meters; 14) inside garage and electrical closet of apartments; 15) installation sites in gas station garage; and 16) wall mounts near grocery store.

Many of the sites were chosen for bad shielding, few were open to the direct transmissions from the Base Station. The raw data is in Appendix B.

Figure 46 plots the data on one graph. The horizontal axis shows the signal strength of the Data signal and the vertical signal strength of the corresponding Voice interferer. Each point represents one of the "installations". The number used at each point (1 to 16) is the number of the site from which the data was obtained. For instance, there are five 1's on the graph representing the five measurements made at site 1.

The graph of Figure 46 shows that the Data signals collected varied from -67dBm to -115dBm in strength. The corresponding interferer levels varied from -63dBm to -114dBm.

On Figure 46, a dotted line represents the line where the Voice level is 13dB higher than the data signal. If the CDI antenna were ideal in all horizontal directions, this would represent the line of no polarization isolation. The transmitted EIRP of the interferer is 13dB greater than the transmitted EIRP of the wanted Data signal.

On the average, the interferer is about 8dB below this line. Thus, even without a very good CDI horizontal antenna, the polarization protection is about 8dB on the average.

In order to correct for the shortcomings of the CDI test antenna, a second graph was made. In this plot, the data points for each location were adjusted for the difference in signal strength measured on the previous day. For example, the polarization entering location 1 had the Voice signal maximum 13dB greater than the Data signal. For graph 47 all the data points for location 1 have been lowered by 13dB on the interferer (Voice) axis. This adjusts the data for differences in EIRP from the central antenna and emphasizes the effect of polarization isolation only.

The adjusted voice level now has the isolation that would occur if equal EIRP's came from both Voice and Data transmissions.

Except for site 15, the results are pretty clear (15 will be treated separately below.) The polarization protection is about 10dB with a standard deviation of about ± 6dB. The distribution is maintained over a signal strength of -60 to -120dBm. This is certainly a useful protection ratio and will give less loss of CDI data if used at an installation.

The case for site 15 is of some interest. In measuring the polarization for the site, it is found that the Voice signal is oriented almost at 45° from vertical (it should be 0°). The Data signal is also fairly well polarized, but at an angle tilted towards the Voice signal polarization. Thus, by mounting the CDI receiver horizontally the interferer is not in fact near a polarization null.

The cause of the rotation of the Voice signal polarization may be related to diffraction over a cliff edge. Site 15 looks down on the Base site building from a cliff. The rotation reduces isolation at this site. The installation measurements were made at a gas station completely obstructed from view and in places shielded by metal structures; the levels varied from -80dBm to -105dBm. The measurements all showed the poor protection from polarization indicating that the polarizations at the hill edge persist into the area behind the cliff.

There are two implications from these results. If no adjustment is made in locations where the Cellular Voice signals are depolarized then there will be statistically more data loss from the reduced protection. The average protection is 10dB, but there will be areas in peculiar terrain where protection is bad.

The second conclusion is that the effect is steady and easily identified. The protection effect was the same over a wide range of installation circumstances in site 15. The polarization isolation is still available; it just doesn't occur on the horizontal. A good null can be achieved by orienting the CDI receiver antenna at about 45° rather than horizontally. For such areas, an installation monitor measuring the Voice signal could be used to install the antenna optimally. Extra installation cost would result, but better protection would be achieved.

(c) Beneath Cell site building

The linear antenna used for the Cellular Voice signal had eight stacked elements giving high gain and narrow (8° beam width) in the vertical plane. It has an omni-horizontal pattern. (See Figure 48. The horizontally polarized antenna used for the CDI test had a single loop. This gives a very wide dipole pattern. At some distance from the Base site the antenna gains differed by about 8dB.

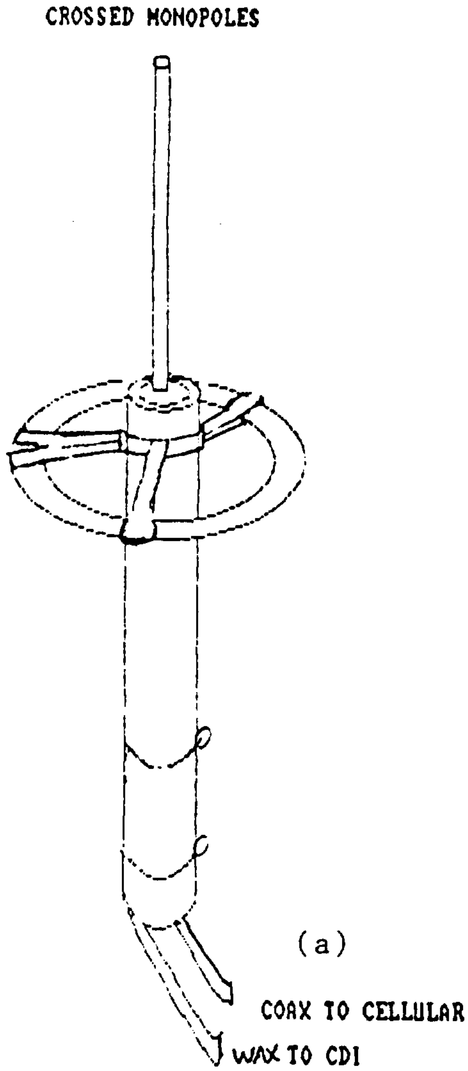
The power radiated from the Vertical antenna was 5dB greater than from the Horizontal antenna. The EIRP on the main axis of both antennas thus differed by 13dB.

However, in the City block around the Mission Valley Test site, the angles are between 20° to 45° down from horizontal. The result of this low angle is that the CDI data signal strength was closer to the level of the Voice interferer and in some cases exceeded it. The relative gain of the two antennas goes from +8dB at 0° to -8 at 40° down from horizontal.

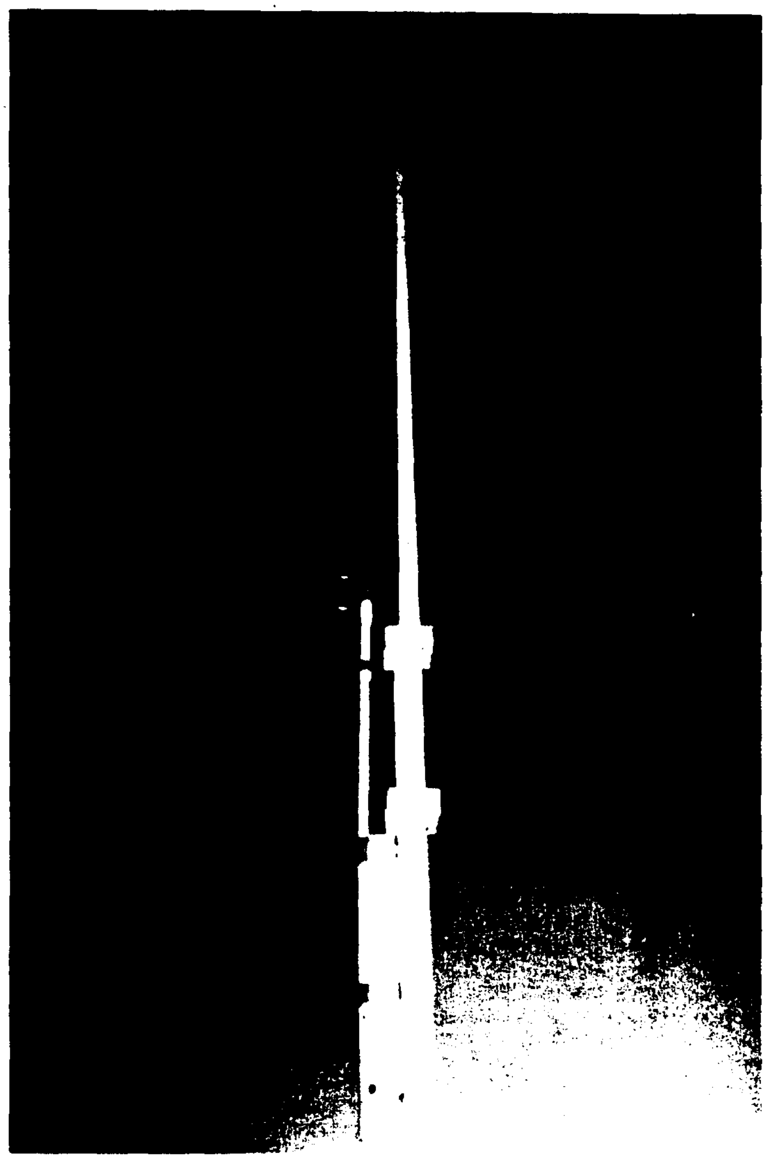
The interference from the CDI signals to the mobiles is too high right near the Base site.

The remedy to the near-base problem is to use a CDI antenna with a second element (or reflector) below it to give a null in the pattern right under the Base site. It is straight forward to accomplish this with standard design. It is important to use this technique to protect the Cellular Voice signal when there are significant User sites within a block or two of the Base station.

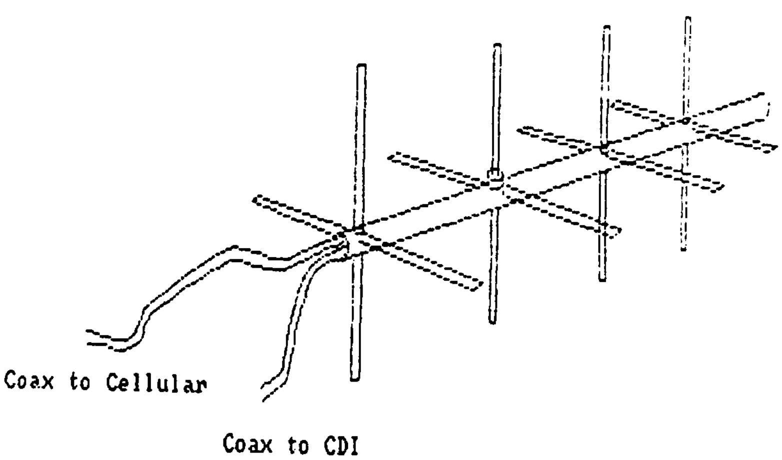
The antenna field pattern in the vertical plane is just as important when the CDI system uses linear vertical polarization instead of horizontal. When the same transmitting antenna is use, patterns, of course, are the same. When different antennas are used, their patterns in the Vertical plane should be fairly well matched (i.e. ± 5dB) from 0° (horizontal) to about 45° down from horizontal.



(a)



(b)



(c)

FIGURE 42
Polarized Antennas

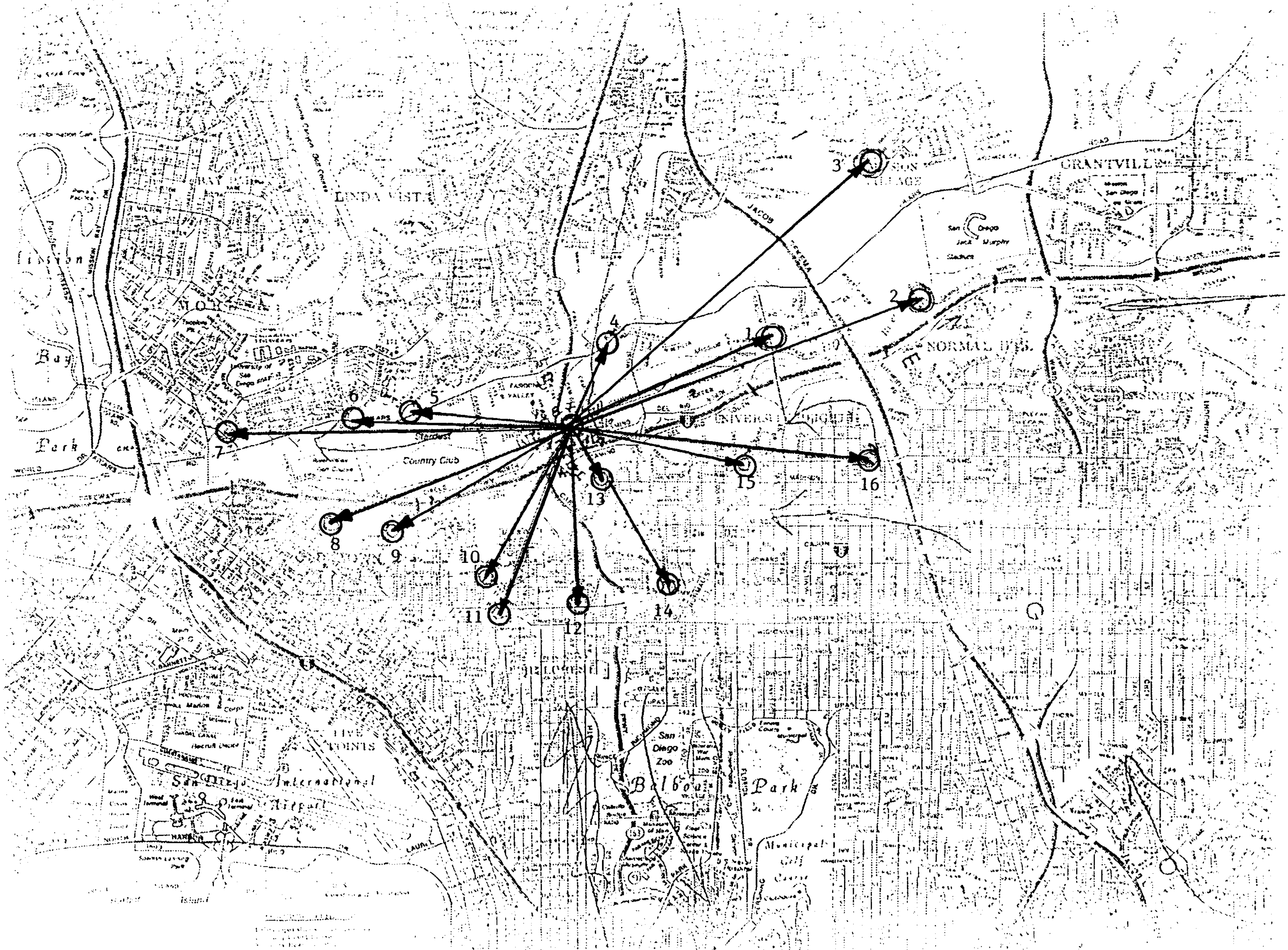


FIGURE 43: Mission Valley Test Locations

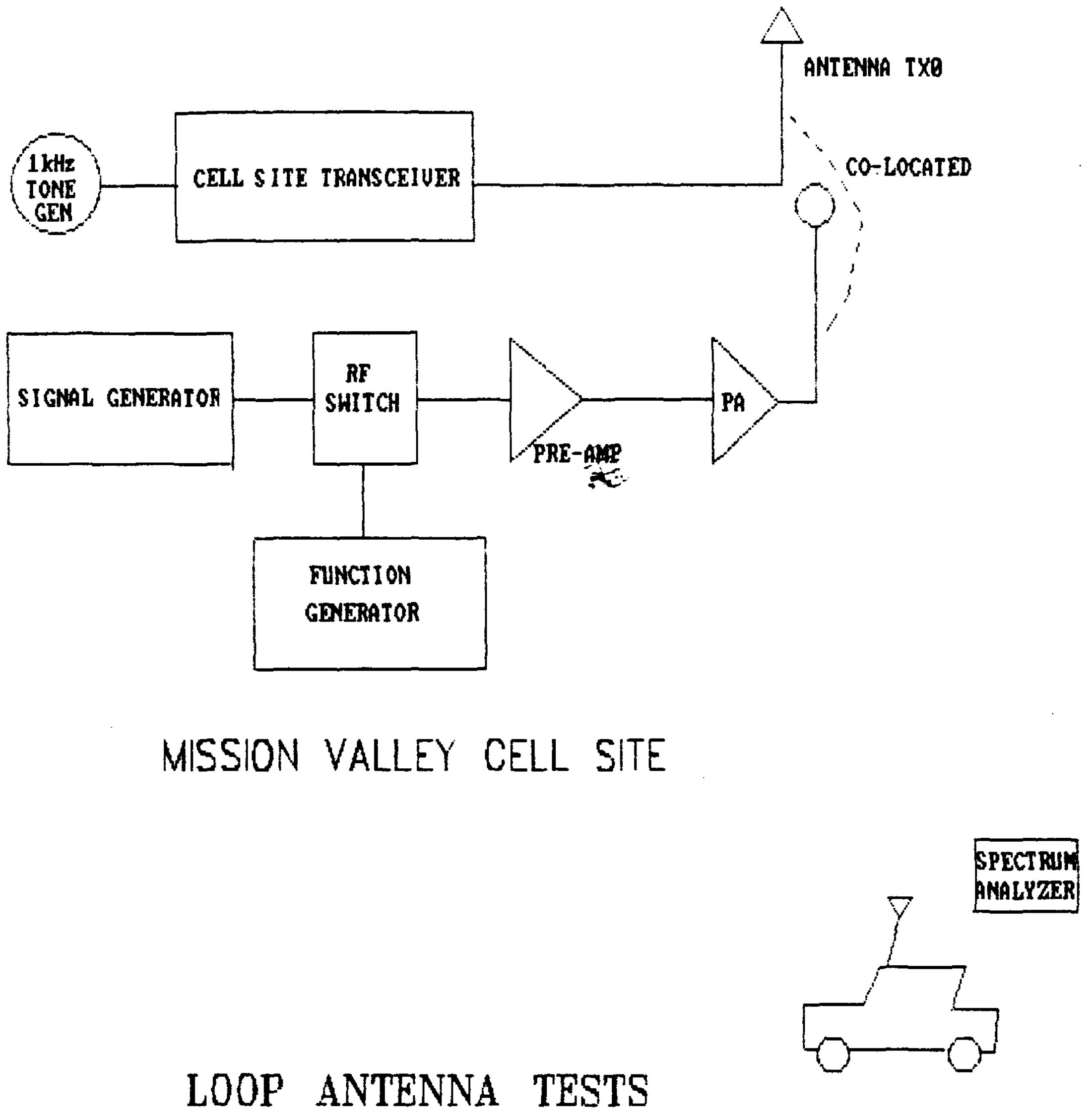


FIGURE 44
Polarization Test Equipment

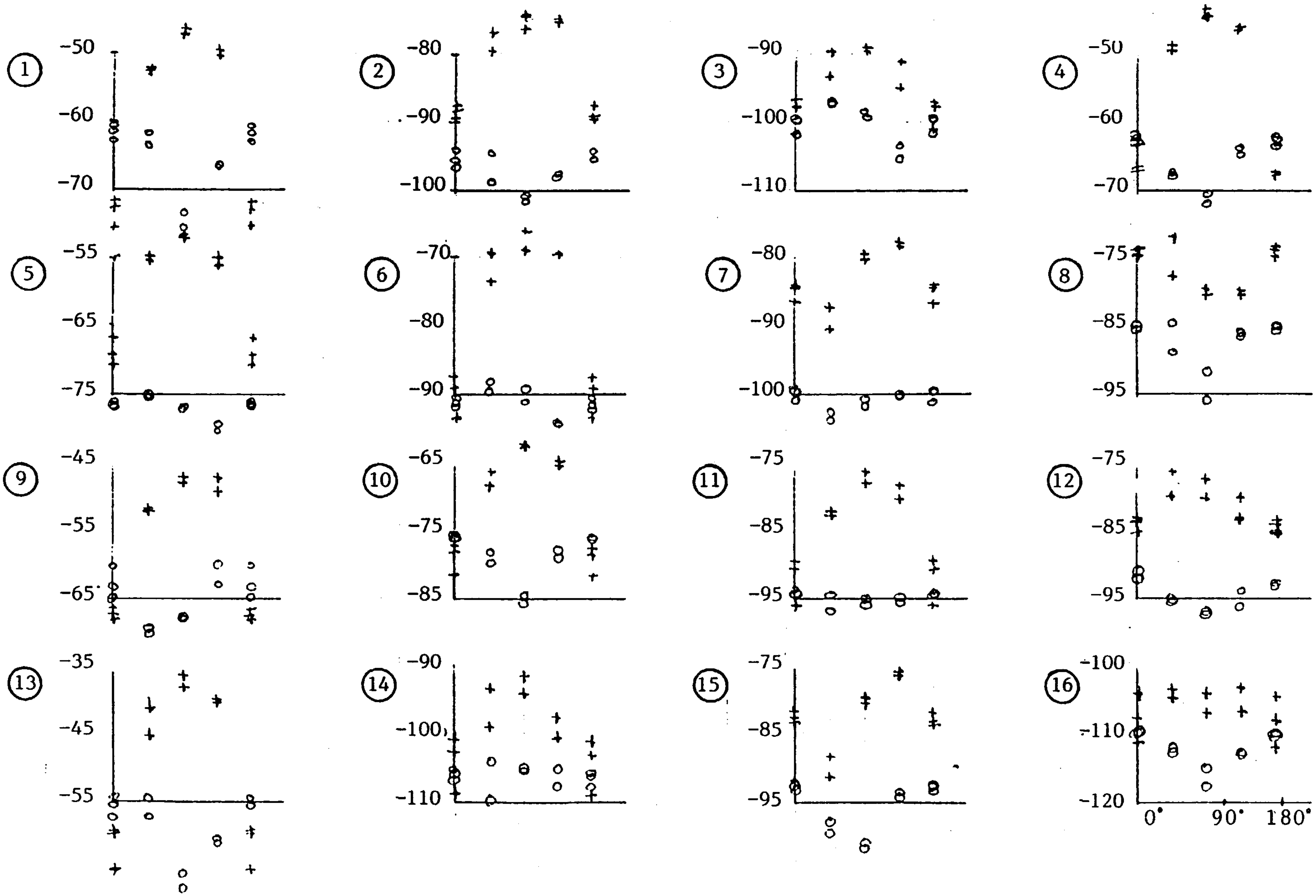


FIGURE 45

Polarization Measurements

T A B L E

Location #	Az	$A_V - A_H$ (dB)	Min A_V (deg)	Min A_H (deg)	Axial Ratio V (dB)	Axial Ratio H (dB)
1	65°	13	0°	90°	33	16
2	67.5	18(weak)	0	90	14	6
3	45	9	0	135	12	6
4	20	18	0	90	22	10
5	272	22	0	135	16	5
6	272	18	0	135	23	6
7	269	22	+45	45	15	4
8	247	12	90	90	10	11
9	240	12	0	45	21	10
10	210	12	0	90	19	10
11	202	16	0	90	18	2
12	180	13	-10	90	9	5
13	167	17	0	90	28	13
14	165	12	0	weak	16	3
15	107	14	45	90	13	9
16	95	5	0	90	weak	12

TABLE A

Polarization Results